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COMPUTATIONAL FLUID DYNAMICS TECHNIQUES FOR MODELLING DUST STORM TURBULENCE PATTERNS IN IRAQ

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Abstract: Considering the various factors that affect dust storms, the independent variables included a set of six meteorological and climatological indicators: wind speed, atmospheric pressure, dust concentration, temperature, humidity, whereas dependent variable, turbulence intensity, was used to measure how turbulent dust storms are examined. Data regarding all the specified variables was accessed from "Geospatial Interactive Online Visualization and Analysis Infrastructure" for a period of twenty years. The findings suggested that there is a meaningful link between the dependent variable and the independent variables for the long-term associations. All have a significant influence on the atmosphere's predisposition to possess the kinetic energy. The significance of this discovery lies in its disclosure of the intricate nature of atmospheric dynamics and their susceptibility to a broad spectrum of external factors. By addressing these obstacles, atmospheric study will progress, and more inclusive models and policies will be developed. Therefore, the current research has also been effective in providing different research implications.

1. INTRODUCTION

Dust storms are a common occurrence in arid and semi-arid regions [24]. Formed in the presence of strong winds gusting over surfaces overlaid by parched soil and lack of vegetation, dust storms befall in areas with low rainfall [18, 20]. Strong winds are

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able to lift the particles in the air which leads to a substantial reduction in visibility; therefore, dust storms predominantly arise from loosened soil [20]. Nevertheless, there are several factors that affect the formation of dust storms. Middleton [22] highlighted the various factors such as soil moisture, duration of drought, human activities, and levels of precipitation along with poor water resource management. Wind plays a critical role in the initiation of the dust storms as particles do not remain stationary when the winds are too strong and a specific threshold is surpassed [24]. At this level of wind speed, particles start to vibrate and move. The movement is dependent on the size, shape, and density of the particles. Particles that are light and finer have the ability to travel a long distance which implies that they can affect areas far away from the initial location [20].

Among the arid and semi-arid regions, Iraq stands as a significant producer of dust [5]. Researchers have explored the variables and sources that influence the dynamics of dust storms and highlighted that 20% of the dust storms occur in three regions: Iran, Iraq and Saudi Arabia [7, 13]. Situated in southwestern Asia, Iraq's weather is characterized as extremely dry and hot in the summers with temperatures exceeding 40 degrees Celsius [5]. The Asian region is known for its emission of dust with 40% of global dust emissions [15]. The long periods of drought cause significant reduction in the vegetation coverage in the region. Consequently, the lack of vegetation coverage results in the aeolian erosion [2]. In the context of Iraq, Halos and Abed [11] discussed that dust storms occurrence amplified with lowered vegetation cover whereas increasing vegetation led to lower frequency of dust storms. Others have acknowledged the role of nearness to desert areas, weather and temperature [5]. Hence, these events exert a significant influence on the well-being of residents in these dry and semi-arid regions while also causing an impact on climate conditions far away from the initial source due to the transportation and deposition of dust by the wind [16]. Dust storms are crucial events providing insights into weather patterns, air quality and public health. This makes it necessary to analyse the dust events and assess the turbulence patterns. Various pollutants can be carried in wind through the dust storms. These include heavy metals, pesticides, bacteria, spores, allergens and gases [5, 8]. As reported by Geravandi, et al. [9], dust storms can cause short-term health concerns among humans, including allergic reactions, respiratory tract infections and long-term issues such as cardiovascular and lung concerns, as well as mortality.

Therefore, given that dust storms are common to dry regions such as Iraq, the present study aims to evaluate the effect of wind speed, atmospheric pressure, dust concentration, temperature, terrain characteristics and humidity on the turbulence intensity in Iraq. Thus, the study utilizes advanced methodological techniques to evaluate the dust storm turbulence patterns in Iraq. To the best of the researcher's knowledge, there are limited studies that have attempted a similar approach in analysis of dust storm patterns in Iraq.

2. Literature Review

Joseph Smagorinsky introduced large eddy simulation (LES) in 1963 to replicate atmospheric air currents; Deardorff (1970) was the first to investigate this turbulence mathematical model used in computational fluid dynamics. LES is being used in a wide range of technical applications, including combustion, acoustics, and atmospheric boundary layer models [27]. When modelling turbulent flows, it is common practice to make computation easier through the use of model in order to reduce complexity regarding turbulence. In this regard, large eddy simulation (LES) is one of the models which reduce the complexity by concentrating on time scales, longer length, and turbulence. The theory postulates, in order to stimulate the dynamic behaviour of dust storm turbulence environment of Iraq. This research looks at the relationship between local temperature and the frequency regarding Iraq's dust storms which tend to conclude that wind speed is the main factor which influence the variability regarding dust emission.

A theoretical gap was identified and addressed through this study where the dust storm turbulence patterns by the method Computational Fluid Dynamics in order to simulate the difficulties and challenges regarding the climatic and geographic circumstance in Iraq. Environmental and geographic characteristics of Iraq have distinct features such as varied atmospheric conditions and landscapes which can impact dust storm dynamically and, which is not taken into consideration in previous studies. In order to depict more realistic pattern of dust storm turbulence and to fulfil this gap CFD (Computational Fluid Dynamics) can provide a valuable insight as compared to any other model which can improve the efficacy of mitigation measures through the unique environmental features of Iraq.

This study delves into intricate the dust storm turbulence patterns in Iraq through the Computational fluid dynamic technique. The study demonstrates the influence, dispersion, and movement regarding dust storm turbulence by examining the complex dynamic sophisticated numerical model in order to check the pattern of the atmospheric environment. To monitor the environment needs to comprehend the dust storm turbulence patterns in order to develop practical implication to reduce the negative influence in Iraq.

In recent years, a number of scholars have examined different facets regarding dust storms postulating as one of the main environmental problems. A study investigates the particle size distribution was tracked, analysed, and correlated in order to encompass the dust storm across 24-hour period determining the speed of the wind. During the same timeframe, they also examined the effects of wind speed changes on the fibre-to-particle ratio during a dust storm. The results show that strong winds, localized near-ground turbulence, and high wind speeds all contribute to the successful lifting of heavier particles during storms, increasing the total quantity of particles [29]. Northern Kuwait saw the highest wind speeds and lowest vision levels, regarding suspended dust for the remaining two days following dust storm. The highest percentage regarding silt and clay determines by the hot spot area regarding the centre and Sabkha areas. Artificial sand dunes and crescent sand dunes postulates the fine sand particles deduction from them [2]. A study determines whether Iraq's dust storm affected by the oscillation of EI Nio-Southern which develop regarding solid synoptic exemption in order to postulate relationship. The results showed a connection between the El Nio-Southern Oscillation and dust storms. This implies that while modest dust storms happen during El Nio episodes, severe dust storms are associated with La Nia. The El Nio-Southern Oscillation and its potential to influence main pressure system values that largely aid regarding the initiation which postulates the intensity in order to determine causes of the relationship for the intensity of dust storms between Iraq's dust storms and tropical pacific region [3].

In Iraq and the arid regions around it, natural disaster condemns by the sand and dust storms which seriously disrupts both the environment and human society. Two sand/dust storms that occurred in May of two different years were analysed in tandem. The NMMB/BSC-Dust model dust surface concentration, regarding satellite vegetation index, seal level pressure, station rainfall and surface wind vector were compared with these sand/dust storms. Storm concentration is lessened by low-pressure gradients, greater rainfall, less severe winds, and an increase in plant cover [12]. In Iraq, rising or stormy dust is not occur but suspended dust is more frequent as compared to them. In the central and southern areas, summertime brought high temperatures and wind

speeds along with an increased frequency of dust outbreaks. Temporal trend distributions of all three kinds of dust occurrences are comparable, showing three distinct periods: rising dust frequency from 1980 to 1993, falling dust frequency from 1993 to 2001, and rising dust frequency once more after 2001 [5]. The synoptic conditions for temperature fluctuations, wind time distribution, and pressure system motions are examined that the dust storm heading into Iraq either gets better or gets less severe [1]. It is very difficult to model due to the complicated terrain regarding Middle East dust storms in order to represent inaccurate characteristics of soil and dust source due to meteorological dynamics of wind speed uncertainties and significant differences in model outputs [14].
The storm formed, developed, and moved due to a low-pressure system, according to the weather maps. The storm's first day demonstrates the dust source region regarding the system development. It also formed two ridges, one of which was located over the north on the storm's second day. The arrangements regarding the two ridges and trough caused the storm for the second and third day and come to a complete halt across northern border of Iraq with Saudi Arabia and southern Iraq. The fourth day storm was pushed to the south of Kuwait and Iraq through the north-westerly wind [21]. It postulates the detrimental effects regarding dust storms on the economy and environment. Dust and sand storms have been more frequent in Iraq which ultimately postulates the trend prediction for the future change in climate [4].
Dust emissions and aerosol dispersion from these sites are now being assessed using in situ field observations and computational fluid dynamics models. Lead and arsenic concentrations in these tailings are high. Mine tailings to the surrounding environment condemn the dust transmission regarding the prediction of the model using computational fluid dynamic model. While regarding the stimulation of tiny aerosols movement used through the dispersion of gaseous plume which examined the paths regarding the larger particles through the use of individual particle transport to keep an eye on where they are being deposited [28].

3. Data and Methodology

3.1 Data

This study is based on the assessment of dust storm turbulence in Iraq which required thoughtful selection of indicators. To measure the turbulent nature of dust storms, turbulence intensity was taken as the dependent variable of the study. The independent variables included a set of six weather and climate-related indicators by considering the various factors that impact dust storms [5]. For this purpose, wind speed was included along with atmosphere pressure, dust concentration, temperature, and humidity. The study also took into consideration terrain characteristic which was measured using surface roughness. The study controls for soil moisture given its importance in dust storms [20]. Data for all the specified variables is taken from "Geospatial Interactive Online Visualization and Analysis Infrastructure" for a period of twenty years.

3.2 Estimation Procedure

The empirical strategy for the current study comprised of a preliminary analysis to assess the characteristics of the variables and verifying the stationarity of the data. Firstly, we employed the LLC test, ADF, PP and Im, Pesaran and Shin test to confirm that the lack of unit root, ensuring that the variables are stable. This is essential to avoid spurious regression [10]. Once the variables become stationarity at first level difference, we can proceed with the use of cointegration estimation method where ordinary least squares (OLS) is the common approach [26]. Nonetheless, the OLS technique is limited when the residuals are correlated, leading to biased estimation. Therefore, a non-parametric approach was proposed, known as the Fully Modified Ordinary Least Squares (FMOLS) technique. The FMOLS technique has gained substantial prominence in literature involving the investigation of long-run relationships [17, 19]. Consequently, it was chosen in the current study for the evaluation of the long-run linkages between the variables.

4. EMPIRICAL FINDINGS

The data was collected for 22 years and thus there were 22 observations for each variable. In addition, the key characteristics of the variables are demonstrated in Table 1 where skewness, kurtosis and Jarque-Bera values are demonstrated for an evaluation of the normality of the variables. The explained variable, TI, exhibits normal distribution with a small JB value and a p-value greater than 0.05. Similarly, DS, HUMID, WIND and SOIL observe a normal distribution. In contrast to this, with a JB value of 201.74 and p-value of 0.00, TEMP is non-normally distributed. ATMPRES and SUR are not normally distributed.

Table 1. Statistical Characteristics.

	TI	DS	HUMID	TEMP	ATMPRES	SUR	WIND	SOIL
Mean	1.427443	5.21E-08	0.004034	2.452763	2.280885	0.035728	5.591352	76.51977
Median	1.386231	4.96E-08	0.004052	2.451539	2.293059	0.035784	5.607611	76.12542
Maximum	1.987459	7.18E-08	0.005733	2.482924	2.348788	0.035785	5.959042	87.44204
Minimum	1.044473	3.46E-08	0.002746	2.445530	2.030191	0.034559	5.154185	68.07762
Std. Dev.	0.249645	1.07E-08	0.000708	0.007138	0.064306	0.000261	0.205268	4.916087
Skewness	0.453643	0.590234	0.540259	3.577839	-2.76895	-4.36433	-0.40135	0.195966
Kurtosis	2.547403	2.514250	3.479244	15.99541	11.68519	20.04747	2.535922	2.468313
Jarque-Bera	0.942345	1.493670	1.280761	201.7440	97.25911	336.2385	0.788057	0.399944
Probability	0.624270	0.473864	0.527092	0.000000	0.000000	0.000000	0.674335	0.818754
Sum	31.40375	1.15E-06	0.088751	53.96078	50.17947	0.786016	123.0098	1683.435
Sum Sq. Dev.	1.308773	2.41E-15	1.05E-05	0.001070	0.086841	1.43E-06	0.884835	507.5262
Observations	22	22	22	22	22	22	22	22

"Note: TI= Turbulent intensity, DS= dust concentration, HUMID= Humidity, TEMP= Temperature, ATMPRES= Atmospheric pressure, SUR= Surface roughness, WIND= Wind speed, SOIL= Soil moisture"

The validation of the absence of a unit root is necessary before proceeding with regression analysis. To achieve this purpose, Table 2 presents the results of the stationarity analysis. At level, the LLC test exhibits that all variables do not have a unit root and therefore, stationarity is validated. Similarly, with a p-value of 0.00, the other unit root tests provide statistical support to the stationarity of the data.

Table 2. Stationarity Analysis.

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-2361.08	0.0000	8	156
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-820.161	0.0000	8	156
ADF - Fisher Chi-square	393.987	0.0000	8	156
PP - Fisher Chi-square	445.833	0.0000	8	168

The FMOLS technique was used to provide a consistent and robust analysis, shown in Table 3. The findings revealed that DS is positively and significantly associated with TI given the p-value of 0.00. Therefore, the association was deemed significant at a high level of significance, providing evidence that increasing dust concentration leads to an increase in turbulence kinetic energy. The outcomes showed that humidity has a positive influence on TI, suggesting that increasing humidity in Iraq contributes to turbulence kinetic energy. The relationship between humidity and TI was supported at a 1% significance level. Similar to this outcome, temperature is positively and significantly associated with TI. This implies that rising temperatures in the country add to the turbulence intensity. On the contrary, atmospheric pressure exert a negative influence on TI, suggesting that high atmospheric pressure lowers TI. The association is statistically significant at a 1% level. The findings also provided statistical support for the association between surface roughness and TI, with a positive and significant association. The speed of wind was shown to be positively related to TI and a statistically significant association was reported. Another inverse relationship was found between soil moisture and TI with soil moisture significantly impacting TI at a 1% significance level.

Table 3. Estimation Results.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DS	46526131.000	2658766.000	17.499	0.000
HUMID	1676.782	58.364	28.730	0.000
TEMP	1785.138	17.597	101.447	0.000
ATMPRES	-13.151	0.941	-13.981	0.000
SUR	10381147.000	63994.780	162.219	0.000
WIND	2.843	0.168	16.878	0.000
SOIL	-0.311	0.007	-43.515	0.000
C	-375823.200	2311.570	-162.584	0.000
R-squared	-367.924	Mean dependent var		1.410
Adjusted R-squared	-566.575	S.D. dependent var		0.242
S.E. of regression	5.765	Sum squared resid		432.067
Long-run variance	0.009			

"Note: DS= Dust concentration, HUMID= Humidity, TEMP= Temperature, ATMPRES= Atmospheric pressure, SUR= Surface roughness, WIND= Wind speed, SOIL= Soil moisture"

We also checked for issues in residuals and whether the assumptions regarding the residuals hold, such as no serial correlation, constant variance, and normality. The outcome for the serial correlation test is presented in Table 4 while heteroskedasticity analysis is exhibited in Table 5. Table 4 discloses the absence of any problem of serial correlation. Similarly, the ARCH test in Table 5 validated that the residuals have constant variance, i.e., they are homoscedastic.

Table 4. Serial Correlation Test.

F-statistic	2.3168	Prob. F (2,12)	0.1410
Obs*R-squared	6.1285	Prob. Chi-Square (2)	0.0467

Table 5. Heteroskedasticity Test.

F-statistic	0.1646	Prob. F (2,17)	0.8496
Obs*R-squared	0.3800	Prob. Chi-Square (2)	0.8270

For appraising the normality of residuals, a histogram is presented in Figure 1. The examination reveals that with a small JB value and high significance level, the residuals adhered to the normality assumption.

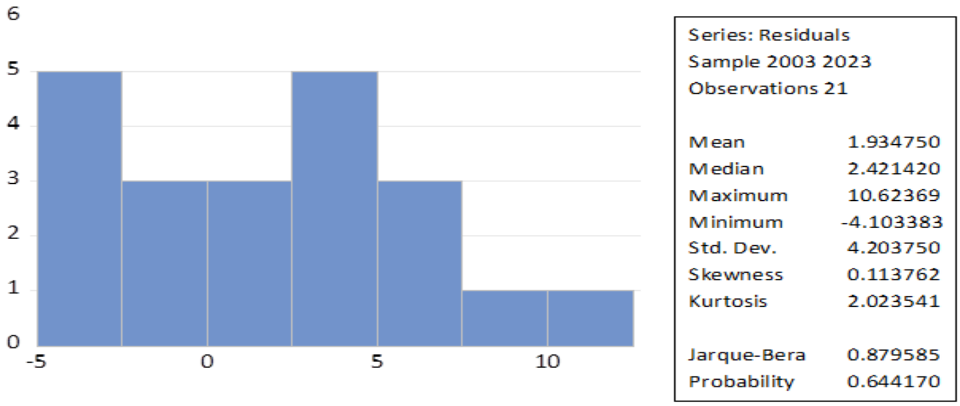

Figure 1. Normality Assessment.

5. Discussion

Dust storms are stated to be an essential natural disaster manifestation. These storms impact the lives of the people, emphasizing increased research within the context of dust storms. This can help in early detection of such storms to prevent any negative aspects. Therefore, dust storms are commonly observed in dry areas, due to increased concentration of dust and atmospheric pressure. Thus, this study aims to determine the impact of wind speed, atmospheric pressure, dust concentration, temperature, humidity on turbulence intensity within the context of Iraq. For this purpose, a secondary quantitative analysis was conducted.

The results obtained from this study showed that dust concentration and humidity have a significant impact on turbulence intensity. It has been observed that diffusion of dust particle and airflow impact the turbulence intensity, leading to the formation of turbulent dust storms. In this regard, diffusion distance of dust and dust concentration largely impact the relative humidity [30]. Therefore, the increased dust concertation as well as humidity in the regions of Iraq often lead to more dust storms. In this regard, increased climate change and temperature are also considered to play an important role. According to Bo [6], heat flux and dust flux are two essential boundary conditions within the forecast model for dust storm. This emphasizes that the higher temperature is likely to increase the dust flux, leading to dust storms. Iraq usually has a higher temperature, making it more vulnerable to dust storms. With the built up of dust over months, percentage errors are observed, which can also prevent an accurate forecast of the related dust storms. Therefore, tailor-made turbines can be installed within these regions which can help in withstanding the rigors of the environment [23]. This approach can also be effective in forecasting the storm dusts more accurately.

Additionally, this study has also highlighted the role of atmospheric pressure in building up dust storms within the context of Iraq due to increased turbulence intensity. Dust storms are usually caused by strong winds in dry regions. In such regions, the atmospheric pressure is also usually found to be higher, which increases turbulence intensity. Opp, et al. [24] have also suggested that sandstorms usually begin in deserted places in which soil moisture is low and wind speed is fast. Other factors such as temperature of sea surface, surface roughness and radiation also influence the formation of dust storms. Moreover, variations within velocity, also influence the turbulent stream [25]. Therefore, this study has been effective in contributing to the literature concerning the impact of wind speed, atmospheric pressure, dust concentration, temperature, humidity, and surface roughness on turbulence intensity within the context of dust storms formation in Iraq. This study has also been effective in providing various theoretical as well as practical implications, which increase its overall efficiency.

6. Conclusion

Iraq has a hot and dry weather, which makes it more vulnerable to dust storms which can negatively impact the quality-of-life and economic conditions within the associated country. Therefore, it has become crucial for the nation to accurately forecast dust storms, in order to prevent any serious damage. In this regard, different factors such as "dust concentration, humidity, temperature, atmospheric pressure, surface roughness, wind speed and soil moisture" can be considered. Therefore, this study also focuses on the role of these factors in determining the turbulence intensity, leading to dust storms in Iraq. The results obtained from this secondary quantitative study show that all factors including "dust concentration, humidity, temperature, atmospheric pressure, surface roughness, wind speed and soil moisture," significantly impact the turbulence intensity, leading to increased formation of dust storms in Iraq. These dust storms negatively impact the overall economic performance of the associated country, leading to insignificant outcomes. In the past research, not much focus has been given on the area under discussion. Thus, the current research has been effective in filling this gap, leading to effective outcomes and research implications.

7. Theoretical and Practical Implications

The understanding of atmospheric dynamics is enhanced by the study, which demonstrates the effects of environmental factors on kinetic energy tendencies. These factors include dust concentration, humidity, temperature, atmospheric pressure, surface roughness, wind speed, and soil moisture. Rejecting the unit root hypothesis highlights the significance of stationary time series data for drawing statistical conclusions in environmental research. The results demonstrate how kinetic energy tendencies are affected by multiple variables, which improves the theory of atmospheric science.

Policymakers and environmental monitors should take note of the study's significant implications. Important elements can reveal weather conditions, which enhances forecasting tools. Based on a thorough comprehension of environmental variables, these insights can assist policymakers in developing strategies for climate adaptation and mitigation. Strong statistical methods used in the study guarantee the accuracy of the results, laying the groundwork for real-world applications in meteorology, environmental management, and the creation of policies to deal with the dynamic changes in the atmosphere.

8. Limitations and Future Research

There are limitations to this study, although it does provide some useful insights. We cannot say for sure how applicable the results are outside of this specific region. More extensive cross-cultural studies involving more regions and countries are needed to remedy these shortcomings. The relevance and applicability of our knowledge of the ways in which various environmental circumstances influence kinetic energy tendencies can be enhanced through cross-cultural comparisons.

The analysis spans the certain period. Longer time periods could be investigated in future studies in order to spot patterns or trends. By including more time, we can strengthen the study's temporal robustness and gain a better grasp of atmospheric dynamics. It is critical to confirm present results in different areas and nations. Result accuracy is susceptible to a wide range of geographical and environmental variables. The intricate connections between environmental factors and kinetic energy trends can be better understood by conducting comparative analyses across different regions. Tackling these limitations will propel atmospheric science forward and contribute to the development of more inclusive models and policies.

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